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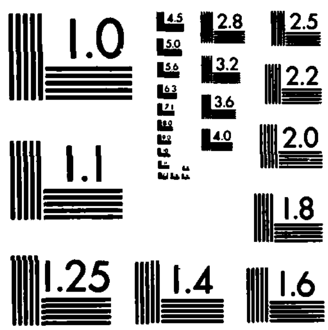

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NRL Memorandum Report 4972

Computer-Controlled Apparatus for the Measurement of the Normal Spectral Emissivity of Materials

J. A. LAFEMINA AND W. E. HOWELL

Off-Board Countermeasures Branch
Tactical Electronic Warfare Division

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NAVAL RESEARCH LABORATORY
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A need exists for the measurement of the thermal radiative properties of materials, especially in the infrared region of the electromagnetic spectrum at moderate to high temperatures. To meet this need, an automated apparatus for the measurement of the normal spectral emissivity from 2-15 μm in the temperature range of 500°C to incandescence has been designed, fabricated and tested. The integral blockbody method was chosen whereby a metallic foil or ribbon is formed into a tube shape and is heated by the passage of direct current. The system

(Continued)

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20. ABSTRACT (Continued)

is described, and sources of error are briefly outlined. Most materials used in engineering systems do not have atomically clean surfaces but come with "as is" surfaces. Hence, one needs to investigate the radiative properties of these real surfaces. Results of the measurement of the normal spectral emissivity of an "as is" tungsten surface from 2-6 μm at 700°C and 900°C are given. The present data is compared with literature values on annealed tungsten samples. These results demonstrate that the present system functions properly and will provide a valuable tool for the rapid assessment of the emissive properties of materials.

CONTENTS

COMPUTER-CONTROLLED APPARATUS FOR THE MEASUREMENT OF THE NORMAL SPECTRAL EMISSIVITY OF MATERIALS

1.0 INTRODUCTION

The optical properties of materials at elevated temperatures have received greater interest in recent years due to technological advances in material fabrication and the search for alternate energy sources. Experimental data characterizing the high temperature optical properties of materials is sparse, and hence a need exists for the measurement of thermal radiative properties of such materials especially in the infrared region of the spectrum at moderate temperatures. This paper discusses one such thermal property, namely emissivity, defined as the ratio of the radiation from the surface of a material to the radiation from a blackbody at the same temperature.

The method of DeVos [1] was chosen to measure the normal spectral emissivity of materials. This method involves the comparison of the radiant intensity normal from a sample tube surface to the radiant intensity from a blackbody hole in the tube wall. Since the blackbody and the sample tube are essentially at the same temperature, one only needs to take the ratio of the radiation from the sample surface and the blackbody to determine the normal spectral emissivity of the sample.

This paper describes a computer-controlled apparatus which has been designed, fabricated and tested to measure the normal spectral emissivity of materials in the infrared region of the spectrum. Some unique features of the emissivity system include:

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1. Blackbody and sample form a single unit at essentially the same temperature,
2. Vacuum or inert atmosphere to eliminate surface contamination,
3. Automatic positioning of blackbody and wall images on entrance slit of monochromators,
4. Automated to ensure rapid data acquisition and reduction,
5. Wide temperature range: 500°C to incandescence,
6. Broad wavelength range: 1-15μm,
7. Solid-state IR detectors for highest sensitivity, and
8. Ease of interchanging samples.

The present system was designed as an engineering instrument for the rapid assessment of the emissivity of materials with tungsten foil chosen as the initial material to test the operation of the system. The tungsten foil, while 99.95% pure, was not annealed and all results presented here are described by an "as is" tungsten surface. The normal spectral emissivity data for the "as is" tungsten surface in the 2-6μm region was approximately 10% higher than annealed samples. Most materials are supplied without any surface preparation and data on the radiative properties of "as is" surfaces will provide useful information for the rapid analysis of such materials.

2.0 DESCRIPTION OF EMISSIVITY APPARATUS

The present system consists of the sample, sample chamber, sample positioner, optical system, and data processing system. Figure 1 shows a schematic of the complete system. Each section will be described in detail.

2.1 Sample

The test sample was fabricated from a one-mil unannealed tungsten foil supplied by the A.D. Mackay Company with a purity content of 99.95%. The tungsten ribbon was then formed into a triangular tube following the method of DeVos except that the blackbody hole was 1.50mm in diameter as opposed to a .3mm

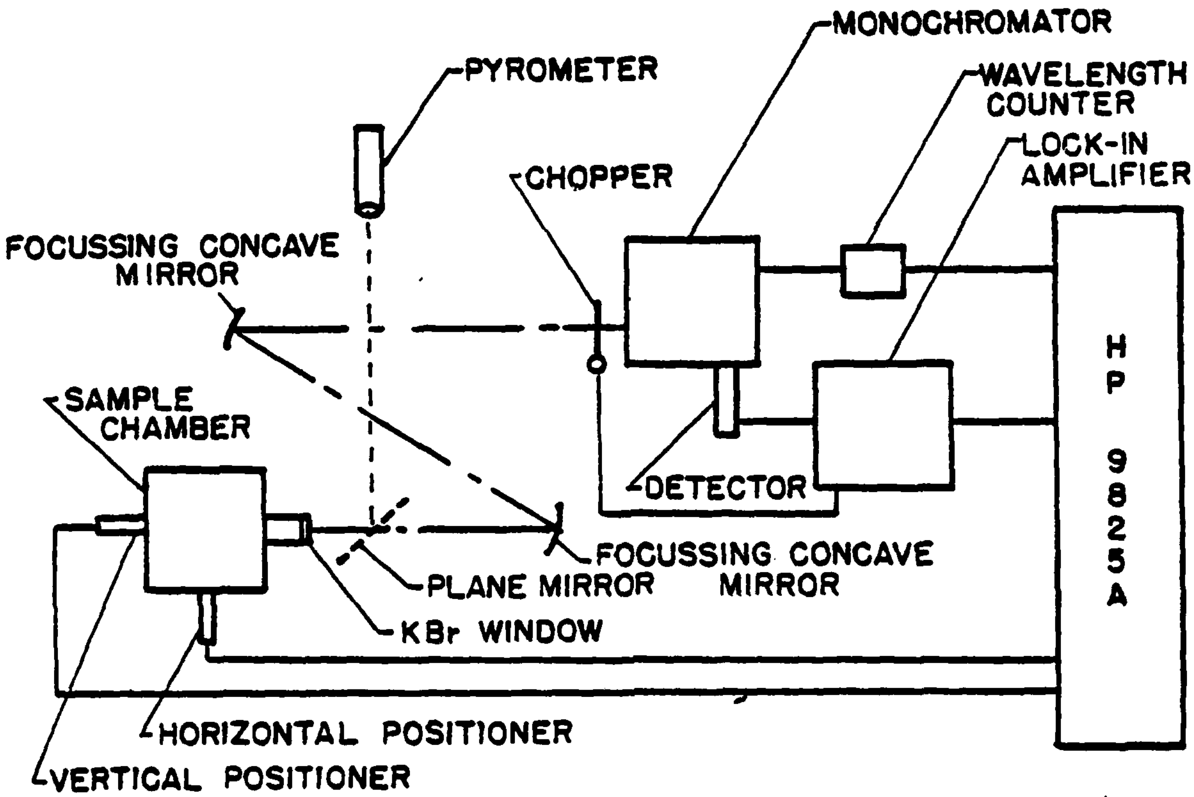

Fig. 1 — Schematic of the emissivity apparatus

diameter. The error introduced reduced the blackbody emissivity from unity to .975 [2]. The blackbody tube dimensions were:

Length:	15cm
Triangular Cross Section:	0.6 x 0.6 x 0.6cm
Wall Thickness:	25μ

Surface roughness measurements made at NRL [3] on the "as is" tungsten foil indicated an average roughness of one micron and waviness amplitude of 15 microns. Auger electron spectroscopy (AES) was used to determine the thickness and composition of any possible surface contaminant. The results showed that the first 200Å is composed of a mixed tungsten carbide-oxide layer and after 200Å-500Å the sample is mainly tungsten. A thin layer of 500Å or less does not influence the surface emission properties of the tungsten sample appreciably. Therefore, the "as is" tungsten surface was virtually contaminant free but not optically smooth.

2.2 Sample Chamber

The design of the sample chamber is shown in Figure 2. The outside body consists of standard stainless steel vacuum components. The chamber was evacuated using an 11 liter per second ion pump with an ultimate pressure of 10^{-8} Torr. The chamber pressure never exceeded 10^{-7} Torr during any of the reported runs. Figure 2 also shows the connections of the tubular sample to the vacuum feedthroughs. The vacuum feedthroughs were oxygen free high conductive (OFHC) copper rods one-fourth inch in diameter which have a maximum current handling capability of 150 amps. These rods were water-cooled which allowed measurements of the tungsten sample at incandescent temperatures. The tungsten tube was first capped on both ends and then tantalum tabs were spot welded to tungsten rods one-eighth inch in diameter, which in turn fitted into set-screw sockets on the copper feedthroughs. A tungsten spring which was needed to absorb the thermal expansion of the tube was spot welded to the lower end of the tube. A platinum, platinum - 10% rhodium thermocouple was placed down

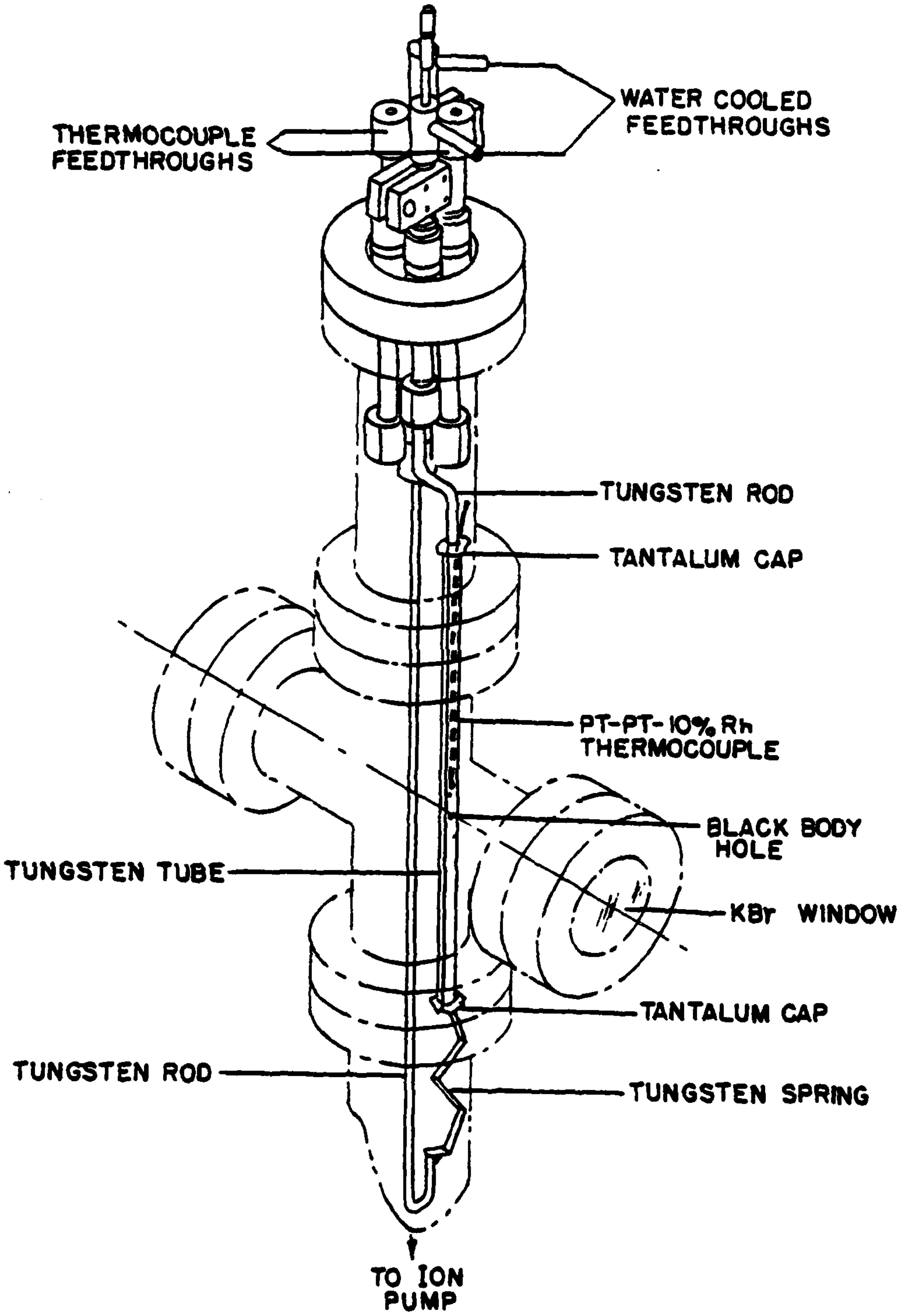

Fig. 2 — View of sample chamber

into the center of the tube to record the tube temperature below incandescence. The thermocouple leads were insulated from the tube by alumina tubing. A Hewlett Packard (HP) power supply rated at 10 volts and 100 amps was used to control the temperature of the sample from room temperature to 1300°C.

2.3 Sample Positioner

In order to measure the intensity from the blackbody hole and the wall the sample chamber had to be aligned relative to the monochromator entrance slit. The sample chamber was mounted on vertical and horizontal linear translation stages as shown in Figure 3. Direct current torque motors were incorporated into these linear stages by means of universal joints, and the limit switches were added to restrict the total linear translation. Relays were placed in between the motor power supplies so that the computer was able to control movement of the translation stage in either direction by controlling the relay on/off times. In this manner linear displacements as small as one mil could be achieved. The fact that the exact position of either translation stage was unknown caused no concern since the intensities of the hole and wall are the important parameters and the lock-in amplifier signal is used in a feedback mode to determine these positions. The blackbody hole position is determined coarsely by aligning the spherical mirrors of the entrance optics and determining a relative maximum on the lock-in amplifier panel meter. The computer then does fine adjustments to locate the blackbody hole more precisely.

2.4 Optical System

In order to image the tube on the monochromator entrance slit, focusing optics consisting of concave mirrors were used as shown in Figure 1. Reflective optics have a dual advantage over refractive optics in that the intensity transmitted is higher and chromatic aberration is absent. The spherical mirrors were used close to axis to minimiz astigmatism and coma, and produced an

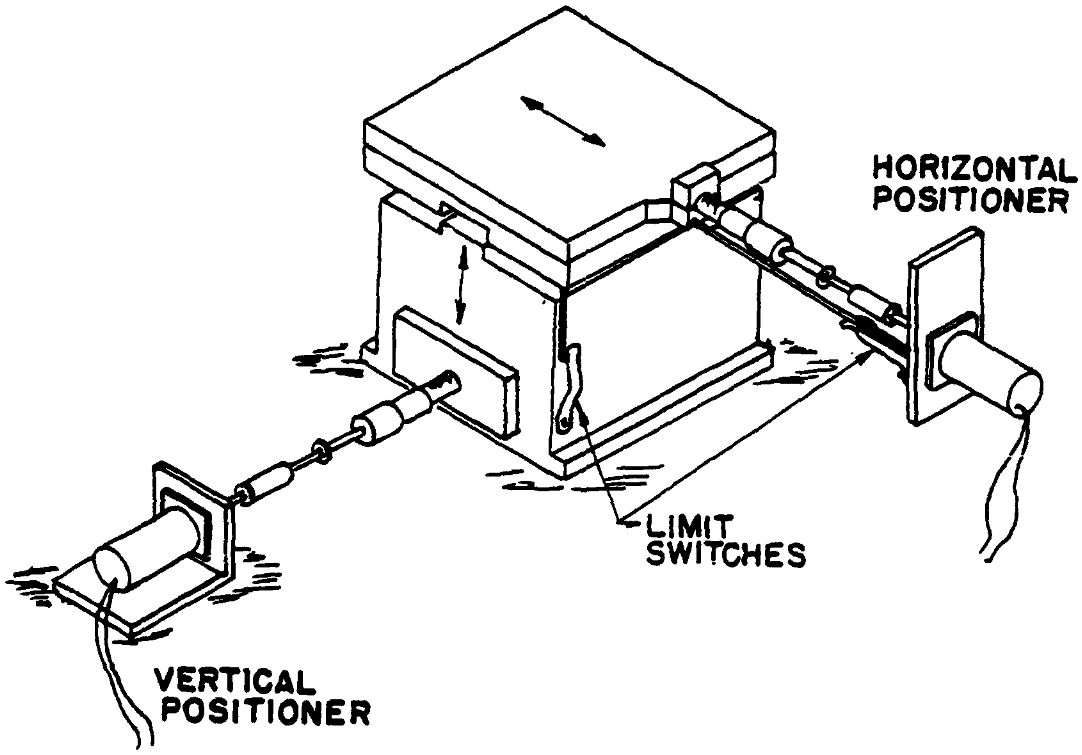

Fig. 3 — Motorized vertical and horizontal translation stages

image of the tungsten tube on the entrance slit with a 2.0 magnification. The arrangement was such that the optics remained stationary and the sample chamber was adjusted for wall and blackbody sampling. The slit on the monochromator was fitted with a circular diaphragm in order to make the image of the blackbody hole larger than the diaphragm opening which enabled the monochromator to sample equal areas of hole and wall. The monochromator was a Spex one-half meter (f/7) and with proper change of grating covers the 2-15μm region. Filters were used to eliminate higher orders from the grating and scattered light. A potassium bromide (KBr) window on the sample chamber allowed high IR transmission in the 2-15μm range. A Barnes pyroelectric detector was initially used since it had a flat spectral response over the entire wavelength region but it's sensitivity was not sufficient for low temperature (<700°C) measurements. Two solid-state IR detectors which increased the sensitivity by a factor of ten were mated to the system. An InSb detector with a 100Hz chopping frequency covered the 2-5.5μm region while a HgCdTe detector with a 1000Hz chopping frequency covered the 5.5-14μm range.

2.5 Data Processing System

The signal from the solid-state IR detector was processed using a PAR Model 186 Lock-In Amplifier and a HP 9825A desk-top computer. A reference signal needed for synchronization was sent to the lock-in amplifier by a PAR Model 192 variable frequency chopper. The HP 9825A computer automatically adjusted the range setting on the lock-in amplifier to give the best signal on the appropriate scale. The values recorded, corresponding to wall and hole intensities, were compiled by the computer and the ratio, i.e. emissivity, was calculated and plotted versus wavelength in real time. In addition, statistical error analyses on wall and hole intensities were calculated and error bars were plotted on the emissivity versus wavelength plots. The HP 9825A controlled all movements of the sample chamber and the wavelength position of the monochromator.

3.0 MEASUREMENT PROCEDURE

3.1 Emissivity Measurements

The first step in this procedure is the fabrication of the tubular sample followed by the mounting of this sample in the vacuum chamber. The blackbody hole is aligned to be normal to the KBr viewing window. The system is sorption-pumped down to $\sim 10^{-3}$ Torr and then the ion pump is engaged to bring the pressure down into the 10^{-8} Torr range. The forepump system is then disconnected and the system is baked out to 125°C. While the stainless steel chamber and sample can withstand much higher bakeout temperatures, the KBr window is limited to 150°C, therefore 125°C was taken as a safe bakeout temperature. The system was given about three weeks of temperature conditioning to allow the sample to reach 1000°C while maintaining a vacuum of no less than 10^{-7} Torr. All runs were taken in the 10^{-7} - 10^{-8} Torr pressure range.

The initial step in acquiring spectral emissivity data was to run the HP 9825A computer with the control program shown in Appendix A. The wavelength counter and the motor positioners of the sample chamber were initialized at the coordinates of maximum signal from the blackbody hole. Thereafter, the computer performed all the functions needed to produce the emissivity plots. The first step is the location of the blackbody hole using a sampling of three consecutive points. The computer moves the horizontal and then the vertical positioner in 16-mil, 4-mil, 2-mil, and 1-mil steps while finding the maximum of three consecutive points. When it has sufficiently located the blackbody hole, the computer averages the detector signal for 200 data points and then samples nine positions about the maximum separated by 1 mil. These points are recorded and averaged as the intensity of the blackbody hole. The positioners then move to upper and lower wall positions, approximately 120 mils from the blackbody hole, and samples nine upper and nine lower wall values. An average wall value is calculated along with its standard deviation. The results are printed out and a point is plotted on the emissivity versus wavelength graph in real time. The computer then moves the wavelength counter to the next wavelength position, repeats this procedure, and continues until the wavelength region of interest is covered. In this way a quick estimate of any significant deviation of the system can be analyzed before proceeding further. The data is then stored on tape in order to be used for additional analyses.

3.2 Temperature Measurement

The temperature of the sample is determined by the platinum, platinum - 10% rhodium thermocouple for temperatures below incandescence and a precision disappearing filament micro-optical pyrometer for temperatures above incandescence. The thermocouple is located inside the sample tube and the optical pyrometer is focused on the blackbody hole. In the region of incandescence, the two methods agreed to within 10°C. The pyrometer was calibrated against standards traceable to the National Bureau of Standards and the maximum uncertainty is ± 3°C. All readings on the pyrometer were corrected for absorption of the KBr window and the plane mirror.

4.0 PRECISION AND EVALUATION OF EMISSIVITY APPARATUS

An absolute estimate of the performance of the present system could not be made due to the lack of suitable emissivity standards; however, estimates of the accuracy and precision of the apparatus were taken from sample, optical, and electronic sources of error.

4.1 Sample

The circular hole in the tungsten tube did not follow DeVos criteria exactly and was not therefore an ideal blackbody. The blackbody correction is a function of wavelength and temperature but the error as discussed previously amounted to no greater than

2.5%. Due to the small thickness of the tube no correction was needed for the difference in temperature between the outer and inner surfaces of the tube. Since temperature gradients along the longitudinal axis of the tube in the vicinity of the blackbody hole were less than 3°C, this error was less than 2.3%.

4.2 Optical

Since the optical path for the blackbody and wall is identical, no error due to the absorption of radiation is possible. The calibration of the wavelength range using the mercury green line was approximately ± .04μm. Scattering within the optical system has been shown to be minimal by other authors using similar designs [4,5].

4.3 Electronic

The measurement of the emissivity requires the ratio of the wall intensity to the blackbody hole intensity. The precision of this measurement is controlled by the signal-to-noise ratio of the data processing system. To calculate the precision, six values at 2μm and six values at 6μm at 700°C were taken and the precision was ± .002 and ± .001, respectively. All runs reported represent an average of at least three trials.

4.4 Performance Summary

Considering all the systematic errors and the precision involved in computing a particular data point as discussed above, the overall evaluation of the present system is better than ± 5% with the major uncertainty in the non-ideal blackbody hole.

5.0 RESULTS AND CONCLUSIONS

As a test for the present system, the normal spectral emissivity of the "as is" tungsten surface at temperatures of 700°C and 900°C from 2-6μm is shown in Figure 4. This tungsten sample was not mechanically polished or annealed, but its surface was cleaned using acetone, methanol, and distilled water. The expected increase in emittance with temperature at wavelengths

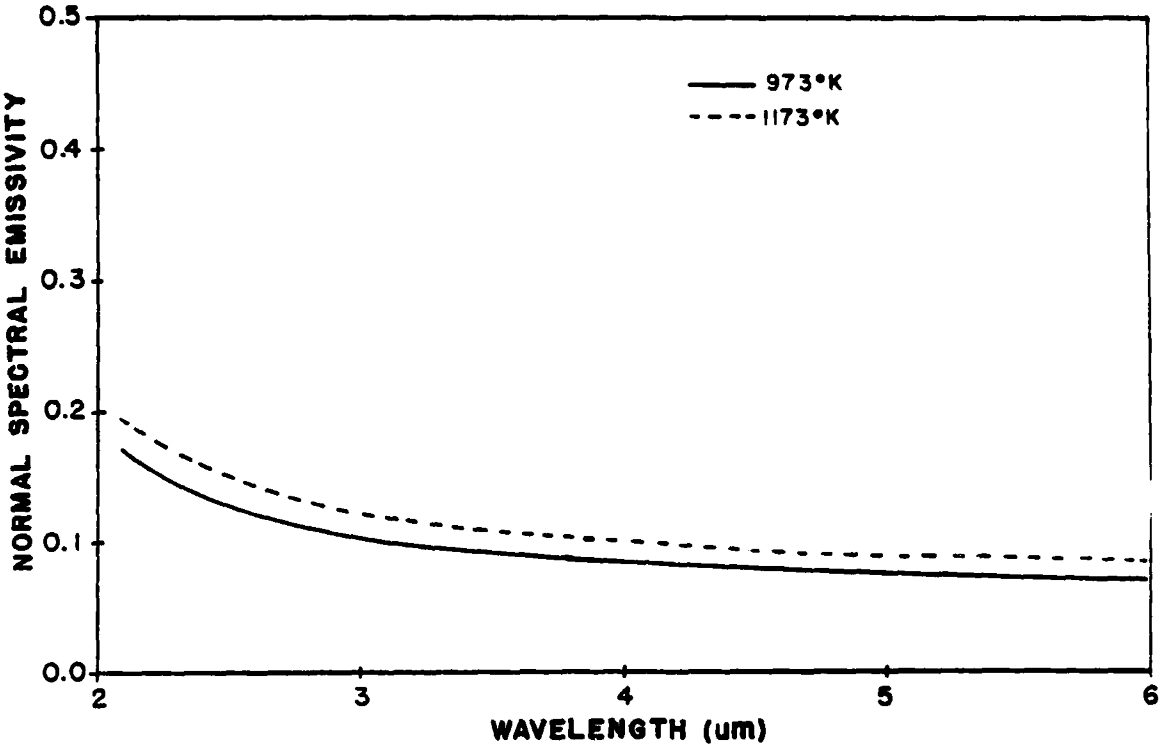

Fig. 4 — Normal specral emissivity vs wavelength for "as is" tungsten

greater than the X-point is clearly shown. Figure 5 shows the comparison of the emissivity of the "as is" tungsten surface at 900°C with previously reported data [5,6] on annealed tungsten surfaces in the 2-6μm region. The error bars on the graph derive mostly from the statistical variations in the wall averaging. These results show that the difference between specially prepared or annealed tungsten and "as is" tungsten is of the order of 10%.

The present automated apparatus which was designed to measure the normal spectral emissivity of materials was successfully tested and its systematic errors identified. It is shown to provide a valuable tool for the rapid assessment of the spectral emissivity of materials. Its future use will involve the investigation of selective emitter coatings and the effect of oxidation on the normal spectral emissivity of materials. This paper presented only the 2-6μm spectral data. The publication of the 6-15μm data is planned in the near future.

6.0 ACKNOWLEDGEMENTS

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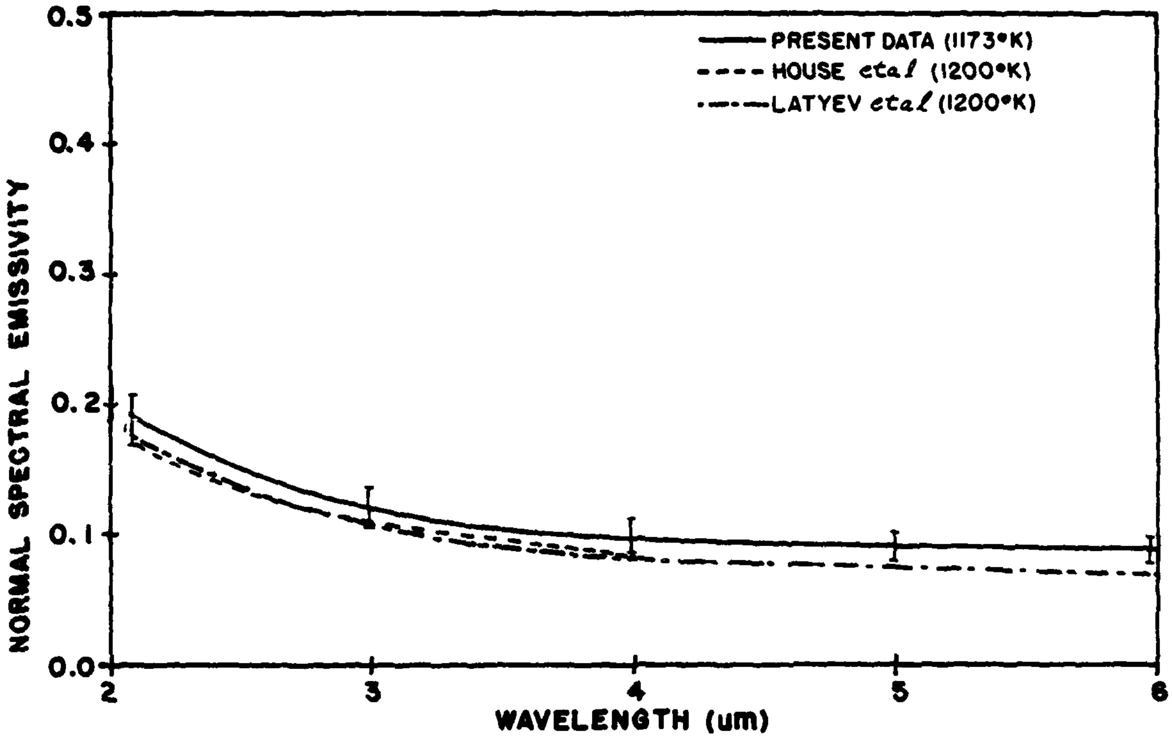

Fig. 5 — Comparison of the normal spectral emissivity vs wavelength of "as is" tungsten with literature values

APPENDIX A

The computer program which controls the emissivity apparatus and calculates the normal spectral emissivity uses HPL, a high level, formula-oriented language. While most of the program is self-explanatory, some special features in the automation process need further explanation. The control of the motorized positioners takes place through relays in the multiprogrammer of the HP 9825A and subroutine SOURCE MOVER controls 20-mil, 10-mil, and 1-mil movements of the horizontal and vertical positioners. Subroutines SETUP WAVELENGTHS and WAVELENGTH MOVER control the initialization and movement of the wavelength drive of the monochromator. Subroutine PEAK FINDER adjusts the positioners until the maximum signal is found on the lock-in amplifier which corresponds to the blackbody hole intensity. Subroutine RANGER automatically adjusts the range scale on the lock-in amplifier in order to determine the most appropriate scale and then subroutine READER takes the values from the lock-in amplifier. The subroutine AREA SAMPLER-WALL goes to upper and lower wall positions and records the average wall intensity. Subroutine PLOT-PEAK and WALL AREA allow the plotting of the emissivity versus wavelength in real time along with error bars based on the standard deviation of the measurement. A copy of the complete program is listed below.

```
0: dsp "EMISSIVITY MEAS. 12/81 -L0!0";clr 723;21→N;wait 5000
1: dim D[30],G[30],A[200],S[50],X[50],Y[50],W[75],E[75],R[75],C[75]
2: gsb "CONSTANTS"
3: gsb "→→→REF POINT"
4: gsb "ALIGN/FOCUS"
5: gsb "SETUP WAVELENGTHS"
6: gsb "EMISSIVITY GRID"
7: for L=1 to int((r81-r80)/r82)+1
8: gsb "PEAK FINDER"
9: gsb "AREA SAMPLER-PEAK"
10: gsb "AREA SAMPLER-WALL"
11: r72/r73/R[L]→L[L]
12: fmt 1,12x,"WLGTH",8x,"EMISS",8x,"BBSIG(nV)",8x,"WALL(nV)";wrt 6.1
13: fmt 2,f16.2,f15.4,f17.0,f15.0
14: wrt 6.2,W[L],E[L],R[L],R[L]E[L]
15: fxd 4;wrt 6,"                    ",(r53+r54)/(R[L]-C[L])-E[L],"+"
16: wrt 6,"                    ",E[L]-(r53-r54)/(R[L]+C[L]),"-"
17: fmt 9,6/;wrt 6.9
18: (r53+r54)/(R[L]-C[L])→S[L]
19: (r53-r54)/(R[L]+C[L])→Y[L]
20: gsb "WAVELENGTH MOVER"
21: gsb "→→→REF POINT"
22: next L
23: gsb "PLOT-EMISSIVITY GRAPH"
24: gsb "PLOT-PEAK & WALL AREA GRAPHS"
25: clr 723;stp ;dsp "Don't forget to rcf"
26: "                                                        ":
27: "                                                        ":
28: "→→→REF POINT":
29: wrt 723,"OB,7,8,1,11,1,T";wait 2000;wrt 723,"OB,7,8,0,11,0,T"
30: wrt 723,"OB,7,6,1T";wrt 723,"IP,2T";red 72301,r93
31: if r93>5;jmp 5
32: wrt 723,"OB,7,8,1T"
33: wrt 723,"IP,2T";red 72301,r93
34: if r93<5;jmp -1
35: wait 2500;wrt 723,"OB,7,8,0T";wait 250
36: wrt 723,"OB,7,9,1T"
37: wrt 723,"IP,2T";red 72301,r93
38: if r93>5;jmp -1
39: wrt 723,"OB,7,9,0T"
40: wrt 723,"OB,7,6,0T"
41: wrt 723,"OB,7,7,1T";wrt 723,"IP,2T";red 72301,r93
42: if r93<5;jmp 5
43: wrt 723,"OB,7,11,1T"
44: wrt 723,"IP,2T";red 72301,r93
45: if r93>5;jmp -1
46: wait 2500;wrt 723,"OB,7,11,0T";wait 250
47: wrt 723,"OB,7,10,1T"
48: wrt 723,"IP,2T";red 72301,r93
49: if r93<5;jmp -1
50: wrt 723,"OB,7,10,0T"
51: wrt 723,"OB,7,7,0T"
52: ret
53: "                                                        ":
54: "                                                        ":
55: "                                                        ":
```

```
56: "RANGER":wrt 723,"OB,7,12,1T"
57: "reset":wrt 723,"IP,2T";red 72301,r93;r93/10→r93;N→M
58: if abs(r93)<.2;N-1→N
59: if abs(r93)>.8;N+1→N
60: if N>21;dsp "out of range";stp
61: if N<2;N+1→N;gto "set"
62: if M-N=0;gto "set"
63: D[N]→C;int(C/16)→r0;int((C-16r0)/8)→r1
64: int((C-16r0-8r1)/4)→r2;int((C-16r0-8r1-4r2)/2)→r3
65: int(C-16r0-8r1-4r2-2r3)→r4
66: fmt 1,5f1.0;fxd 0;dsp r0,r1,r2,r3,r4
67: for I=0 to 4
68: if rI=0;1→rI;jmp 2
69: if rI=1;0→rI
70: next I
71: wrt 723,"OB,7",0,r0,1,r1,2,r2,3,r3,4,r4,"T";wait 5000;gto "reset"
72: "set":wrt 723,"OB,7,12,0T";ret
73: "                                                                    ":
74: "                                                                   ":
75: "READER":beep;0→r90;0→r91;wrt 723,"OB,7,12,1T"
76: for I=1 to 200;wrt 723,"IP,2T";red 72301,A[I];r90+A[I]/10→r90;next I
77: r90/200→r90
78: for I=1 to 200;(A[I]-r90)↑2+r91→r91;next I
79: √(r91/200)→r91;wrt 723,"OB,7,12,0T";ret
80: "                                                                    ":
81: "                                                                   ":
82: "CONSTANTS":
83: 5→D[1];100→G[1];6→D[2];200→G[2];7→D[3];500→G[3]
84: 9→D[4];1000→G[4];10→D[5];2000→G[5];11→D[6];5000→G[6]
85: 13→D[7];10000→G[7];14→D[8];20000→G[8];15→D[9];50000→G[9]
86: 17→D[10];1e5→G[10];18→D[11];2e5→G[11];19→D[12];5e5→G[12]
87: 21→D[13];1e6→G[13];22→D[14];2e6→G[14];23→D[15];5e6→G[15]
88: 25→D[16];1e7→G[16];26→D[17];2e7→G[17];27→D[18];5e7→G[18]
89: 29→D[19];1e8→G[19];30→D[20];2e8→G[20];31→D[21];5e8→G[21]
90: ret
91: "                                                                    ":
92: "                                                                   ":
93: "SOURCE MOVER-20R":
94: if H>0;gsb "right20"
95: if H<0;gsb "left20"
96: if V<0;gsb "up20"
97: if V>0;gsb "down20"
98: ret
99: "right20":for I=1 to H
100: wrt 723,"OB,7,8,1T";wait 2080;wrt 723,"OB,7,8,0T";wait 250;next I;ret
101: "left20":for I=1 to -H
102: wrt 723,"OB,7,9,1T";wait 2180;wrt 723,"OB,7,9,0T";wait 250;next I;ret
103: "up20":for I=1 to -V
104: wrt 723,"OB,7,10,1T";wait 2240;wrt 723,"OB,7,10,0T";wait 350;next I;ret
105: "down20":for I=1 to V
106: wrt 723,"OB,7,11,1T";wait 2280;wrt 723,"OB,7,11,0T";wait 250;next I;ret
107: "                                                                    ":
108: "                                                                   ":
109: "                                                              ":
110: "                                                                   ":
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```
111: "SOURCE MOVER-10R":
112: if H>0;gsb "right10"
113: if H<0;gsb "left10"
114: if V<0;gsb "up10"
115: if V>0;gsb "down10"
116: ret
117: "right10":for I=1 to H
118: wrt 723,"OB,7,8,1T";wait 1040;wrt 723,"OB,7,8,0T";wait 250;next I;ret
119: "left10":for I=1 to -H
120: wrt 723,"OB,7,9,1T";wait 1090;wrt 723,"OB,7,9,0T";wait 250;next I;ret
121: "up10":for I=1 to -V
122: wrt 723,"OB,7,10,1T";wait 1120;wrt 723,"OB,7,10,0T";wait 350;next I;ret
123: "down10":for I=1 to V
124: wrt 723,"OB,7,11,1T";wait 1140;wrt 723,"OB,7,11,0T";wait 250;next I;ret
125: "                                                                      ":
126: "                                                                      ":
127: "                                                                     ":
128: "                                                                      ":
129: "                                                                      ":
130: "SETUP WAVELENGTHS":
131: ent "Start wavelength (um)=?",r80
132: ent "End wavelength (um)=?",r81
133: ent "Wavelength interval (um)=?",r82
134: if r80>=2.1 and r81<=4;gto "2.1-4"
135: if r80>=3.5 and r81<=6;gto "3.5-6"
136: if r80>=6 and r81<=12;gto "6-12"
137: if r80>=12 and r81<=15;gto "12-15"
138: gto "NOrun"
139: "2.1-4":spc ;spc ;prt "Need grating# 150g/mm"
140: spc ;spc ;prt "Need filter#L02007-8"
141: 8→r83;gto "ok"
142: "3.5-6":spc ;spc ;spc ;prt "Need grating# 150g/mm"
143: spc ;spc ;prt "Need filter#L03092-9"
144: 8→r83;gto "ok"
145: "6-12":spc ;spc ;spc ;prt "Need grating# 75g/mm"
146: spc ;spc ;prt "Need filter#L06093-9"
147: 16→r83;gto "ok"
148: "12-15":spc ;spc ;spc ;prt "Need grating# 75g/mm"
149: spc ;spc ;prt "Need filter#L10832-9"
150: 16→r83;gto "ok"
151: "NOrun":spc ;spc ;prt "No single filter grating for this range";spc ;spc
152: beep;dsp "          RUN STOPPED";wait 999;dsp " ";wait 200;jmp 0
153: "ok":fxd 0;dsp "Set counter to ",10000r80/r83;r80→W[1];stp
154: ret
155: "                                                                      ":
156: "                                                                      ":
157: "WAVELENGTH MOVER":
158: wrt 723,"WF,6.2,2500,T,OP,6",1e6r82/r83,"T";dsp "Moving wavelength"
159: for I=1 to 10;wait 2.6e5r82/r83;next I;dsp " "
160: W[L]+r82→W[L+1];wait 2600
161: ret
162: "                                                                      ":
163: "                                                                    ":
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164: "EMISSIVITY GRID":
165: int(r80)-1→r85;int(r81)+1→r86
166: fxd 3;dsp "Set P1 → (0,",r85,")";stp
167: fxd 3;dsp "       Set P2 → (1,",r86,")";stp
168: prt r85,r86;scl r85,r86,0,1;fxd 0
169: xax 0,1,r85,r86,1;plt (r85+r86)/2,-.1,1
170: csiz 2,2,1,0;lbl "WAVELENGTH";fxd 1
171: yax r85,.1,0,1,1;plt r85-.5,.5,1;csiz 2,2,1,90
172: lbl "EMISSIVITY"
173: plt r85,1,-2;plt r86,1,-2;plt r86,0,-2;plt r80,0,1
174: ret
175: "
176: "
177: "
178: "
179: "SOURCE MOVER-1R":
180: if H>0;gsb "rightH"
181: if H<0;gsb "leftH"
182: if V<0;gsb "upV"
183: if V>0;gsb "downV"
184: ret
185: "rightH":wrt 723,"OB,7,8,1T";wait 104H;wrt 723,"OB,7,8,0T";ret
186: "leftH":wrt 723,"OB,7,9,1T";wait -109H;wrt 723,"OB,7,9,0T";ret
187: "upV":wrt 723,"OB,7,10,1T";wait -112V;wrt 723,"OB,7,10,0T";ret
188: "downV":wrt 723,"OB,7,11,1T";wait 114V;wrt 723,"OB,7,11,0T";ret
189: "
190: "
191: "
192: "PEAK FINDER":16→r63;0→r64;0→r98;0→r99
193: fmt 8,3f10.0,4f7.3
194: for O=1 to 3
195: r63→H;r64→V;gsb "SOURCE MOVER-1R"
196: gsb "RANGER"
197: wait 2000;gsb "READER"
198: G[N]r90→r62;-2r63→H;-2r64→V;gsb "SOURCE MOVER-1R"
199: gsb "RANGER"
200: wait 2000;gsb "READER"
201: G[N]r90→r60;r63→H;r64→V;gsb "SOURCE MOVER-1R"
202: gsb "RANGER"
203: wait 2000;gsb "READER"
204: G[N]r90→r61
205: fxd 0;dsp r98,r99;if max(r60,r61,r62)=r61;jmp 13
206: if max(r60,r61,r62)=r60;jmp 2
207: jmp 5
208: -r63→H;-r64→V;gsb "SOURCE MOVER-1R"
209: r98-r63→r98;r99-r64→r99;gsb "RANGER"
210: wait 2000;gsb "READER"
211: r61→r62;r60→r61;G[N]r90→r60;jmp -6
212: if max(r60,r61,r62)=r62;jmp 2
213: jmp 5
214: r63→H;r64→V;gsb "SOURCE MOVER-1R"
215: r98+r63→r98;r99+r64→r99;gsb "RANGER"
216: wait 2000;gsb "READER"
217: r61→r60;r62→r61;G[N]r90→r62;jmp -12
218: if r63=0;jmp 2
219: r63→r64;0→r63;jmp -24
220: r64/4→r63;0→r64;next O
221: 0→r50;0→r51;0→r52
222: for O=1 to 10
```

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223: gsb "READER"
224: G[N]r90+r50→r50;G[N]r90→X[O];G[N]r91+r51→r51;next O
225: fmt 5,2/,"Peak Avg(nv) =",f10.0,"+-",f8.0
226: for O=1 to 10;(X[O]-r50/10)↑2+r52→r52;next O
227: r50/10→R[L];r(r52/10)→C[L]
228: wrt 6.5,R[L],C[L]
229: ret
230: "
231: "
232: "AREA SAMPLER-WALL":0→r72;0→r73;0→r75;0→r51;0→r52
233: 5→V;-2→H;gsb "SOURCE MOVER-20R"
234: fmt 2,1/,"    upper samples",/;wrt 6.2
235: fmt 3,f10.0,z
236: for K=1 to 3;1→r65;3→r66;1→r67;1→H
237: if frc(K/2)=0;3→r65;1→r66;-1→r67;-1→H
238: for J=r65 to r66 by r67
239: gsb "RANGER"
240: wait 2000;gsb "READER"
241: wrt 6.3,G[N]r90;G[N]r90+r72→r72;1+r73→r73
242: r91+r51→r51;G[N]r90→X[r73]
243: 0→V;gsb "SOURCE MOVER-20R"
244: next J
245: 0→H;-1→V;gsb "SOURCE MOVER-20R"
246: wrt 6;next K
247: r75+1→r75;if r75>=2;gto 253
248: N+2→N;gsb "RANGER RESET"
249: -2→H;-3→V;gsb "SOURCE MOVER-20R"
250: -2→H;-3→V;gsb "SOURCE MOVER-20R"
251: fmt 4,2/,"   lower samples",/;wrt 6.4
252: gto 236
253: fmt 4,1/," avg sample=",f10.0,"+-",f8.0
254: for O=1 to r73;(X[O]-r72/r73)↑2+r52→r52;next O
255: r72/r73→r53;r51/r73+r(r52/r73)→r54
256: wrt 6.4,r53,r54
257: N+5→N;gsb "RANGER RESET"
258: ret
259: "
260: "
261: "ALIGN/FOCUS":
262: dsp "CONTINUE if reference focused";stp
263: ret
264: "
265: "RANGER RESET":
266: D[N]→C;int(C/16)→r0;int((C-16r0)/8)→r1
267: int((C-16r0-8r1)/4)→r2;int((C-16r0-8r1-4r2)/2)→r3
268: int(C-16r0-8r1-4r2-2r3)→r4
269: fmt 1,5f1.0;fxd 0;dsp r0,r1,r2,r3,r4
270: for I=0 to 4
271: if rI=0;1→rI;jmp 2
272: if rI=1;0→rI
273: next I
274: wrt 723,"OB,7",0,r0,1,r1,2,r2,3,r3,4,r4,"T"
275: ret
276: "
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```
277: "AREA SAMPLER-PEAK":0→r77;0→r78;0→r55;0→r56
278: -1→H;1→V;gsb "SOURCE MOVER-1R"
279: fmt 2,1/," Peak Samples",/;wrt 6.2
280: fmt 3,f10.0,z
281: for K=1 to 3;1→r57;3→r58;1→r59;1→H
282: if frc(K/2)=0;3→r57;1→r58;-1→r59;-1→H
283: for J=r57 to r58 by r59
284: gsb "RANGER"
285: wait 2000;gsb "READER"
286: wrt 6.3,G[N]r90;G[N]r90+r77→r77;1+r78→r78
287: r91+r55→r55;G[N]r90→X[r78]
288: 0→V;gsb "SOURCE MOVER-1R"
289: next J
290: 0→H;-1→V;gsb "SOURCE MOVER-1R"
291: wrt 6;next K
292: N+2→N;gsb "RANGER RESET"
293: fmt 4,1/," Avg Peak sample=",f10.0,"+-",f8.0
294: for O=1 to r78;(X[O]-r77/r78)↑2+r56→r56;next O
295: r77/r78→r68;r55/r78+√(r56/r78)→r69
296: r68→R[L];r69→C[L]
297: wrt 6.4,R[L],C[L]
298: ret
299: "
300: "PLOT-PEAK & WALL AREA GRAPHS":
301: dsp "READY PLOTTER FOR PEAK GRAPH";stp
302: int(r80)→r85;int(r81)→r86
303: scl r85,r86,0,1;fxd 0
304: xax 0,1,r85,r86,1;plt (r85+r86)/2,-.1,1
305: csiz 2,2,1,0;lbl "WAVELENGTH"
306: fxd 1;yax r85,.1,0,1,1;plt r85-.5,.5,1;csiz 2,2,1,90
307: lbl "IR OUTPUT"
308: plt r85,1,-2;plt r86,1,-2;plt r86,0,-2;plt r80,0,1
309: max(R[*])→r79
310: for I=1 to L-1;plt W[I],R[I]/r79,-2;next I
311: dsp "READY PLOTTER for WALL GRAPH";stp
312: for I=1 to L-1;plt W[I],R[I]E[I]/r79,-2;next I
313: ret
314: "ERROR BAR":
315: plt W[I],E[I]+(S[I]-E[I]),-2
316: pclr;cplt -.33,-.25;lbl "-";cplt -.67,.25
317: plt W[I],E[I],-2
318: plt W[I],E[I]-(E[I]-Y[I]),-2
319: pclr;cplt -.33,-.25;lbl "-";cplt -.67,.25
320: plt W[I],E[I],-2
321: ret
322: "PLOT-EMISSIVITY GRAPH":
323: dsp "READY PLOTTER FOR EMISSIVITY GRAPH";stp
324: for I=1 to L-1
325: plt W[I],E[I],-2
326: gsb "ERROR BAR"
327: next I
328: ret
*2455
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